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Utilizing BIM and Carbon Estimating Methods for Meaningful Data Representation

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Abstract

The building sector releases 36% of global CO₂ emissions, with 66% of emissions occurring during the operation stage of the life cycle of a building. While current research focuses on using Building Information Modelling (BIM) for energy management of a building, there is little research on the visualizing building carbon emission data in BIM to support decision makings during operation phase. This paper proposes an approach for gathering, analyzing and visualizing building carbon emissions data by integrating BIM and carbon estimation models, to assist the building operation management teams in discovering carbon emissions problems and reducing total carbon emission. Data requirements, carbon emission estimation algorithms, integration mechanism with BIM are investigated in this paper. A case is used to demonstrate the proposed approach. The approach described in this paper provides the inhabitants important graphical representation of data to determine a buildings sustainability performance, and can allow policy makers and building managers to make informed decisions and respond quickly to emergency situations.

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1. Introduction

1.1. Motivation

The building sector is responsible for consuming about 40% of global energy and releases 36% of global CO₂ emissions [1]. CO₂ emissions are a major contributor to global climate change [3].

More than 66% of the carbon emissions from a building occur during the operation stage of the life cycle of a building [1]. The most effective changes to reduce a building's carbon output are: increasing the service life span and reducing the energy consumption per building area [1]. Recently, more and more regulations have been developed globally that aim to target building emissions [4].

1.2. Building Information Modelling (BIM)

Building Information Modelling (BIM) is a system that is used by the architecture, engineering and construction (AEC) sector for integrated preplanning, design and project delivery of new buildings [2]. BIM is an object based, multidisciplinary analysis tool, used in pilot projects in the early 2000s [2]. It differs from tradition computer aided design (CAD) in that it is object intelligent, meaning it presents information for specific objects within a building, such as doors or columns [6]. BIM has been used in projects for 3D visualization, shop drawing generation, cost estimating and construction sequencing, among other uses [7].

1.3. Objective

While some current research focuses on using BIM technology for energy management of a building, there is little research on the use of BIM for carbon estimation of buildings that produces results that are localized and in real time. This paper includes a literature review of current uses, drawbacks and possible future uses of BIM, identifies the research gap, defines the scope of the research and presents an approach for the real time carbon estimating and representation of data in BIM. A discussion of results and future areas of research is then presented in the conclusion.

2. Literature Review

2.1. Current Applications of BIM in Different Phases

According to recent data from the Aconex platform (a widely used system in the AEC industry for information management), 30% of construction projects around the globe are now using BIM [8]. In North America, the use of BIM in AEC projects has increased from 28% to 71% between 2007 and 2012 [8]. Countries such as Japan, Germany, France and Canada have also reported large positive returns on investment (as high as 97%) from using BIM technologies in AEC projects [8]. Although BIM use has been expanding, it has not been doing so at the expected rate due to data interoperability issues and the lack of a standardized method that provides instructions on the application and use of BIM [7].

However, these statistics do not reflect the use of BIM throughout the life cycle of a building. In recent research, it is eminent that BIM is not being widely used past the construction phase [2]. The lack of BIM use has been attributed to the lack of data input and documentation into the BIM model (if existing) to represent the “as-built” design because there is no automated method of doing so [2]. The great difficulty of a shift to the full life cycle use of BIM is justified by pointing out the many benefits such as quality control, energy management and retrofit planning, among others [2]. Another problem is that many existing buildings have never used a BIM model in their design process, specifically old buildings. A “lightweight BIM” has been suggested, which involves creating a BIM model with only necessary information for the remainder of the buildings life cycle management [9].

The term “Green BIM” has become increasingly popular in recent literature, described as a “model-based process of generating and managing coordinated and consistent building data during its project lifecycle that enhance building energy-efficiency performance, and facilitate the accomplishment of established sustainability goals” [5].

The main issues in current green BIM literature are the lack of effort for use past construction, lack of “cradle-to-grave” environmental simulation and insufficient use of cloud computing technology existing in BIM [5].

The use of BIM beyond the design phase is heavily related to the ease of which new data can be input into the BIM models [2]. Buildings with sensors and smart meters generate large amounts of data [10]. BuildingSMART, an international non-profit, has developed Industry Foundation Classes (IFC) standards which aim to create an international format for the exchange and sharing of building information data [11]. IFC is a freely available program representing a data schema that allows data to be shared across different software applications by the industry throughout the life cycle of a building, including BIM [11]. Another schema that has been developed, Green Building XML (gbXML), also facilitates the transfer of data between BIM models and engineering analysis tools [12]. This schema allows for less time consuming and costly engineering analysis of BIM models, and allows analysis data to be put back into the BIM models [12]. IFC standards can also be combined with Data Warehouse technology to process and classify building data gathered by sensors and smart meters [10]. This data can then be used for analysis using other programs, such as MATLAB [10].

2.2. Applications of BIM for Energy Aspects during Operation Stage

Although few, applications do exist that allow for carbon emissions studies and predictions of a building's performance in the design phase, such as Autodesk Green Building Studio [5]. There also exist applications that automatically transform BIM models into models that are compatible with Building Energy Models (BEM) which allow for the simulation of a building's life cycle energy use [13]. Both of these applications use prediction models, but the environmental performance of a building is seldom as predicted. No software exists that uses BIM and real time measurements together for the assessment of a buildings environmental performance as of yet.

A model has been developed for real-time recording of important indicators of carbon emissions that can be used to calculate the energy use of a building using Radio Frequency Identification (RFID) technology [14]. This model uses embedded RFID in building materials, which can be used to take measurements of key indicators such as quantity use of building material (commonly estimated), electricity use and fuel use through the lifecycle of a building. There are new research studies underway on the input of information into BIM models throughout a buildings life cycle, such as “SocioBIM”, a system that requires user input from buildings residents to monitor performance and maintenance [15].

2.3. BIM for Facility Management

Energy consumption increases when a building is poorly maintained, resulting in higher levels of emissions [1]. Research shows that BIM technology can be used to improve Facility Management (FM) of buildings, and therefore prolong the operation stage and reduce energy consumption [16]. Benefits of using BIM for FM include improved information flow, risks mitigation and performance monitoring [2]. For example, Northumbria University in the United Kingdom (UK) has used BIM in FM to monitor, track and update locations of asbestos in the building [17].

3. Research Gap & Scope

Currently, there is little research on using both BIM and carbon estimating methods to present a building's carbon data in real time, and localizing the carbon data within a building. This type of research can result in important graphical representation of data to determine a buildings sustainability performance, and can allow policy makers and building managers to make informed decisions and respond quickly to emergency situations.

For the purpose of this paper, only residential buildings will be focused on, because residential buildings are the dominating emitter in the building sector (77% of building sector CO₂ emissions in Europe) [1]. Many carbon estimating methods focus on the entire life-cycle of a building (or product) to achieve an accurate representation of the environmental impact [18], but only the operation stage of the life cycle of a building will be used as it accounts for 66% of the emissions of a residential building [1]. This will also allow real time modelling of the carbon emissions as well as localized emission data. Within the operation stage, only the direct and embodied carbon

dioxide emissions of electricity use and natural gas usage are accounted for. A general overview on the transfer between building data from BIM and the carbon estimating data is described, but details on the schema are outside the scope of this paper.

4. Approach of Integrating Real-time Carbon Emission Estimation with BIM

4.1. Methodology

The following methodology combines carbon estimating methods and BIM to produce carbon emissions data. Figure 1 provides a diagram representing this methodology. Sensor data is taken from the building then is input into the carbon estimating method to achieve carbon emissions data, which is then combined back with the BIM model for meaningful data representation in BIM.

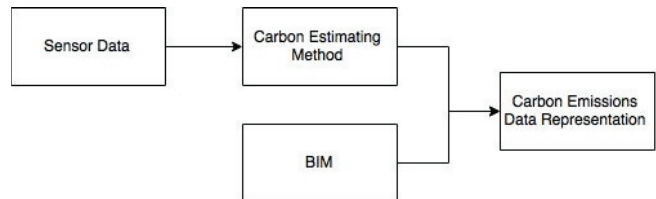


Fig. 1. Diagram Representing the Methodology

4.2. Carbon Estimating

The main source of carbon emissions of a building during the operation stage is the consumed energy [1]. Consumed energy can come from multiple sources such as natural gas and electricity, which itself can come from many different sources with different carbon emissions.

To properly account for all carbon emissions, the following three step framework is suggested [18]: 1) Selection of greenhouse gases, 2) Setting a boundary and 3) Collection of data. For this study, step 1 and 2 are simple, the focus is on Carbon Dioxide gas, CO₂. The boundary for this study is the direct and embodied emissions *produced by energy consumption and natural gas usage during the operation stage* of a building.

For the collection of data, most buildings are built with sensors (or utility meters) that produce real time readings of the electricity usage of the whole building in kilo watts (kW) or, depending on the time step of the sensor data, kilo watt hours (kWh) [9]. For buildings without sensors installed, the emergence of new technology which make wireless sensors more affordable is a promising advancement that will allow implementation of sensors into old buildings affordable [19]. Once this electricity consumption data is collected, it can be multiplied by the carbon density of electricity, which shows the amount of CO₂ released per KWh of electricity used (mass/kWh).

$$C_{Elec} = (\sum_{i=1}^n E_{Consumed,i}) \times Y_{Carbon,ave} \quad (1)$$

Where C_{elec} is the total carbon emissions due to electricity use (mass CO₂), $E_{Consumed}$ is the electricity consumed of type i (kW or kWh) and Y_{Carbon} is the average carbon density of electricity. Because the source of electricity changes with respect to time of generation and location, it is recommended to use real time energy generation data that is region specific to determine a realistic carbon density factor. For example, at this current time (2-3AM in Toronto on Monday, June 29th) the average carbon density factor is 24g/KWh, which is fairly low due to the time and sources of electricity [20]. In regions where this data is not available on an hourly updated basis, the closest time increment found is used, such as average carbon density per day, month or even year.

When natural gas consumption data is collected from meters, generally in Joules (J), it can be multiplied by 5×10^{-8} kg CO₂/Joule to determine the CO₂ emissions [21]. This number does not change depending on time or location and is a constant, as it is a direct emission of carbon.

$$C_{Natural Gas} = G_{Consumed,i} \times 5 \times 10^{-8} \quad (2)$$

Where $C_{Natural\ Gas}$ is the total carbon emissions due to natural gas use (kg CO₂), $G_{Consumed,i}$ is the amount of natural gas consumed (Joules) and 5×10^{-8} kg CO₂/Joule is the carbon density of natural gas. Table 4.1 summarizes the above required table and provides possible sources of data.

Table 1. Summary of Data Required.*

Data Required	Units	Possible Sources
Electricity Usage	<i>Kilowatts (kW) or Kilowatt-Hours (kWh)*</i> *If using kW, an hourly average must be calculated.	Building Sensors or Utility Meters
Carbon Density of Electricity (by type if available, average if not)	<i>Mass/kWh*</i> *Where “Mass” can be <i>grams (g)</i> or <i>kilograms (kg)</i> depending on given data.	Online Indexes such as GridWatch [20], Government Resources such as the United States EIA (Energy Information Administration) or directly from Energy Companies
Natural Gas Usage	<i>Joules (J)</i>	Building Sensors or Utility Meters

*Note: Data should be available in real time measurements.

4.3. Transfer of Data Between BIM and the Carbon Estimating Process

This methodology requires the exchanging of data between BIM models, sensors and the carbon estimating method. The carbon estimating method requires BIM and sensor data, including the location and range of the sensors as well as their readings. Once the carbon estimating model is complete, this data needs to be input back into the BIM model for the representation of data.

In order to acquire necessary data from BIM models, IFC standards support different objects in specified domains [10]. The IFC objects that may be relevant to this study, dependent on the building and extensity of the BIM model, are outlined in the following table.

Table 2. IFC BIM objects needed for analysis.

Information Required	IFC Objects
Spatial (To allow for spatial recognition of emissions levels within a building)	IFCBuildingStorey
	IFCSpace
	IFCBuilding
Electricity Usage	IFCSensor/IFCSensorType
	IFCDistributionFlowElement
	IFCDistributionCircuit
	IFCFlowMeter
Natural Gas Usage	IFCSensor/IFCSensorType
	IFCDistributionFlowElement
Time (This will include real time stamping of measurements from sensors)	IFCPerformanceHistory
	IFCTimeSeries

The objects in Table 2 are used to extract the needed information from the BIM model to be input into the carbon estimating method. IFCSensor, for example, is defined as “a device that measures a physical quantity and converts it into a signal which can be read by an observer or by an instrument” [11]. IFC objects can be connected to each other using indicated IFC relationships. To get electricity usage information from a sensor for example, IFCSensor can be connected to IFCDistributionFlowElement, which is defined as “elements of a distribution system that facilitate the distribution of energy or matter, such as air, water or power” [11]. The “signal” from a sensor is the data necessary for the carbon estimating model, but when extracted from IFCSensor, the data is generally given as numerical values that needs to be analyzed and filtered [11]. Especially when dealing with large amounts of continuous, real-time data, the filtering of data is very important.

Many different methods have been produced to deal with extracting and managing sensor data from BIM models. A few of these methods are outlined here:

- IFC objects can be analyzed and filtered using third party parsing tools together with a Data Warehouse technology, which use a central repository of data from different sources for data analysis, in order to manage the vast amounts of data being extracted from BIM [22].
- BIM software development kits (SDK) could be used to parse and read BIM data, or standalone BIM tools can be developed for the same purpose [23].
- A problem that arises when attempting to extract data from sensors is the many different protocols and formats of sensors that are developed [9]. A web service information approach can be used to remedy this, as the Open Geospatial Consortium (OGC) has specified standards for interoperability encodings to allow for the real time integration of different sensor webs [9].
- An “Addition and Absorption (A&A) Method” can be used to deal with data from IFC objects and store it into tables to be input into data mining algorithms [19]. This method links tables of data by category of element, attribute and value [19].

Using one of these methods, or others that may be applicable, the retrieving and sorting of data into desired outputs from IFC objects is achievable. Once the data is sorted and ready to use, it can be input into the carbon estimating equations using any software such as MatLAB to calculate the mass of CO₂ emitted.

The next step is to input the carbon estimation data back into the model, as values of “mass CO₂”, to be presented in the BIM model. One popular BIM application is Autodesk Revit, which in itself cannot represent real time data but can be used with add-ins to do so [24]. Add-ins have been developed that utilize BIM spatial data (such as IfcSpace) with real time data inputs to display on 2D graphs of physical structures, where more work is underway to create a Revit add-in to allow for 3D data plots directly onto the BIM model [24]. Alternatively, a new IFC Property Set can be developed to allow for 3D representation in BIM models using existing IFC objects and text editing software to be input back into the BIM model [25].

4.4. Representation of Data in BIM

Once the carbon data is calculated, it can be integrated into BIM in order to create meaningful representation. The carbon emissions data can be localized within a building, using BIM’s information on the location coverage of electricity and natural gas sensors, therefore creating a dynamic BIM model that can interact with the real time carbon data. An example of a possible data representation is shown in Figure 4.2.1, where the red areas represent areas that are releasing high amounts of carbon. High amounts are a factor of how much electricity and natural gas is being used, and also the carbon intensity of electricity generation at that time. Depending on the region where the building is located, the average carbon emissions can be calculated and set at the medium value, to which high and low can be compared. If the building is aiming to lower emissions, the medium carbon emissions value can be set lower. The carbon emissions can vary by floor level or even by room, depending on the location and coverage of sensors in a building.

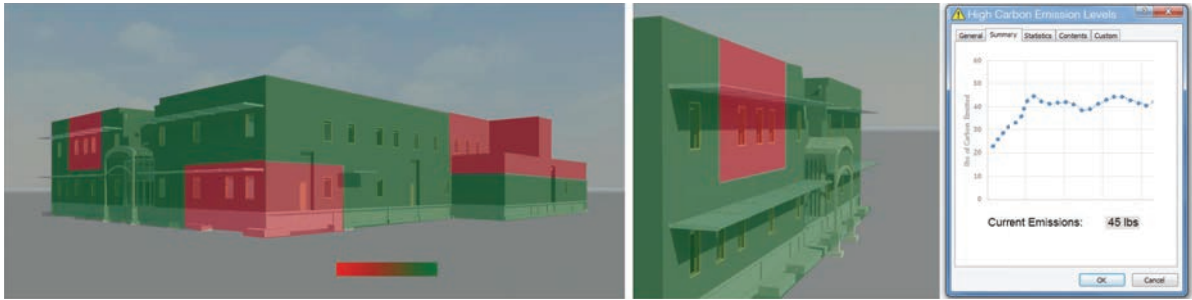


Fig. 2. Examples of Possible BIM Interface with Carbon Emissions

5. Discussion and Conclusion

5.1. Possible Uses & Further Expansion of Research

Calculating and representing carbon emissions is becoming increasingly important as countries are setting goals to reduce global carbon emissions to prevent disastrous effects of climate change. There are many ways that the real time representation of carbon emissions data in BIM can be utilized. As mentioned, this system can allow facility managers to react to emergencies in a timely manner and to determine a priority list of necessary repairs. Facility Managers are responsible for monitoring the system, and can use the BIM model to do this when real time data is displayed.

Carbon policies are also becoming increasingly important. This data representation can be used by environmental policy makers to see what average carbon emission levels are in their specific regions, allowing them to make informed decisions on things such as implementing carbon pricing mechanisms down to the individual household/unit level and caps on total carbon emissions per buildings.

This kind of real time data representation can also be used by energy supplying companies for billing down to the individual unit level in condominiums and apartments, which is currently not widely done [26]. This type of billing would encourage inhabitants to consume less and therefore lower emissions, as smart metering has proven to reduce electricity by 20% in residential buildings [26].

This data can also become viewable to occupants of residential buildings. Allowing occupants to see their environmental performance compared to others within their place of dwelling has proven more reliable reductions in electricity utilization by users [27]. This allows occupants to understand the scope of their carbon emissions relative to an average of the area, and compared to other residents within the building, which is much more effective than providing just their individual usage (as is done currently with electricity meters).

As mentioned above, the specifics of the data transfer between BIM and carbon estimating methods are only highlighted but have not yet been implemented in this paper. This research can be used as a framework/recipe for the implementation of this methodology. This methodology can also be expanded to cover other types of emissions from different processes that occur in residential buildings that have an environmental impact, and to cover emissions to the individual appliance level if necessary. This same methodology can also be expanded to be used for other types of buildings, such as retail or industrial, as it can now only be applied to residential buildings. Other forms of representation of carbon data in the BIM model can also be developed.

5.2. Conclusion

Carbon emissions reductions have become increasingly important in the AEC industry. BIM is used in the design and construction phase of the life cycle of a building, but not used widely beyond that. This paper presents a methodology that combines carbon estimating methods and BIM technology to allow for real time, spatial representation of carbon emissions data within a building. The approach described in this paper provides important graphical representation of data to determine a buildings sustainability performance, and can allow for the decrease in carbon emissions through facility managers, policy making, carbon pricing and the sharing of performance data.

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